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AUTHOR	Romberg, Thomas A.; Collis, Kevin F.
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ABSTRACT

The purpose of this study was to identify the working memory capacity (M-space) for a group of 139 children (4 to 8 years of age) enrolled at Sandy Bay Infant School in Hobart, Tasmania, Australia. Four M-space tests -- The Counting Span Test (Case and Kurland, 1978), Mr. Cucui Test (DeAvila and Havassy, 1974), the Digit Placement Test (Case, 1972), and The Backward Digit Span Test (Hiebert, 1979) -- were administered to the children. Using four different scoring rules for each test, it was found that the context of test may give students a cue which helps them answer questions above their M-space level, that there is no abrupt shift or change in M-space, and that some children appear to incorporate a strategy of chunking information in order to solve problems beyond their indicated M-space level. Cross tabulation of the four tests indicated that children classified into an M-space level by one test would not necessarily be classified into the same level using another test. Analysis revealed one primary factor reflecting quantitative skills and another reflecting spatial perception. The principal conclusion of this study is that with some qualifications children can be grouped by test scores into well-defined sets with similar working memory capacities. (Author/MP)

Technical Report 540

The Assessment of Children's M-Space

by

Thomas A. Romberg
University of Wisconsin

and

Kevin F. Collis
University of Tasmania

The Research Committee of The University of Wisconsin Graduate School

Wisconsin Research and Development
Center for Individualized Schooling
The University of Wisconsin
Madison, Wisconsin USA

The University of Tasmania, Hobart, Tasmania, Australia

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Abstract

This paper reports the results of the first of a series of collaborative studies examining how young children acquire the skills to represent and solve verbal addition and subtraction problems. The purpose of this study was to identify the working memory capacity (M-space) for a group of children. Four M-space tests were administered to 139 children of ages four to eight who were enrolled at Sandy Bay Infant School in Hobart, Tasmania.

The data derived from the tests were examined in three ways. First, each response was scored four ways: number correct, partial level, absolute level (based on partial level) and absolute level (based on number correct). The different scoring rules made it apparent that there is no abrupt shift or change in M-space level, that the context of a test may give students a cue which helps them answer questions above their M-space level, and that a few children appear to incorporate a strategy of chunking information so they could solve problems beyond their indicated M-space level.

Second, the relationship of the absolute level scores for the four tests were examined. The correlation of the test scores, while all positive, were not particularly high. Pairwise cross tabulations of scores showed that the tests classify children in different ways. A factor analysis of the test correlations revealed one primary factor which reflects quantitative skills. The second, and less important factor was suggested which reflects a spatial perception.

Third, since no one test is adequate to classify individuals into an M-space level, cluster analyses was used. This analysis yielded six groups of children. The contextual setting of a test, number or spatial orientation

has a significant effect on the child's ability to respond. Spatial development and number development appear to be interwoven and occur close together in time, but some groups achieve number skill prior to spatial skill and others vice versa. The six groups identified will be used in the later studies of how children learn to solve verbal addition and subtraction problems.

This paper reports the results of the first of a series of related, collaborative studies examining how young school children acquire the skills to represent and solve a variety of verbal addition and subtraction problems. The evolution of children's performance on these skills is related both to their cognitive abilities and to their engagement in related instructional activities. The purpose of this study was to identify the working memory capacity of a group of children of ages four to eight. This memory capacity or "M-space" is hypothesized to be critical to cognitive development, and identifies a major difference in cognitive processing ability among individuals.

The Collaborative Studies

This series of studies is jointly funded by the Research Committee of the Graduate School at the University of Wisconsin, the University of Wisconsin Research and Development Center for Individualized Schooling, and the University of Tasmania. The principal investigators of the studies brought different backgrounds and skills to this collaborative effort. The identification of cognitive abilities grows out of Professor Collis' extensive work in cognitive development (for example, see Collis and Biggs, 1979, Note 1). The classroom engagement ideas stem from Professor Romberg's research on teaching (see Romberg, Small, and Carnahan, 1979).

The strategy adopted for the sequence of collaborative studies has five steps:

1. Identify M-space for a population of children of ages 4-8.
2. Identify "cognitive processing capabilities" for the same set of

children.

3. From (1) and (2) identify a well-defined set of children with specific cognitive characteristics, assess their performance, and determine the strategies they use when solving addition and subtraction problems.

4. From (3) identify a sample of children and observe their engagement in instructional activities on related tasks for three months.

5. Repeatedly measure, on three occasions over the three month period the sample's performance and note the strategies they use with addition and subtraction problems.

This procedure will allow us to relate performance (in terms of level achieved and strategy adopted) at a given time to the child's cognitive capability and to the specific set of instructional activities the child is engaged in. In this way we can consider various questions about change in performance and strategy and their possible causes.

This Study

The need for a measure of M-space is rooted in the theory of Pascual-Leone (1970, 1976). The rationale for giving a set of different tests to measure the construct is based on the results of a recent study (Hiebert, 1979), where the measure of M-space (Backward Digit Span) proved not to be predictive of learning mathematical skills. The other three tests administered in the present study were adapted from those used by Case and Kurland (1978, Note 2). This study could be considered a replication of Case and Kurland's study on a larger sample. In all, four tests were given and their concurrent validity was examined.

Pascual-Leone's Theory

Although there are substantial differences among information processing theories, they are all based on the idea that mental functions can be characterized in terms of the way information is stored, accessed, and operated upon. Mental structures are discussed in terms of an intake register through which information from the environment enters the system, a working or short-term memory in which the actual information processing occurs, and a long-term memory in which knowledge is stored. For this series of studies the most critical structural component is the working memory, because it is the locus of processing.

The working memory's growing capacity to process information is a fundamental characteristic of cognitive development (Bruner, 1966; Case, 1978c; Flavell, 1971). Young children are quite limited in their ability to deal with all the information demands of complex tasks. Their limited capacity may be a critical developmental factor which constrains learning in instructional situations (Case, 1975, 1978a, 1978b).

Pascual-Leone (1970, 1976) proposed a theory which operationalizes the development of this information processing capacity or M-space. According to this theory, learning is a change in behavior resulting from factors extrinsic to the psychological system. Learning produces a change in the repertoire of schemes (internally represented behavioral units or patterns) available to the subject. Since M-space is limited, the number of information chunks which can be coordinated to produce a new scheme is limited. Therefore, the complexity of learned schemes is also limited. In this way the processes of learning are constrained by the developing psychological system.

Pascual-Leone's theory is concerned with the functional aspects of development and the temporal mental processing of information. Learning through instruction depends on the child's capacity to process all of the essential incoming information.

In order to generate hypotheses about children's performance on specific tasks, both (a) the information processing capacity (M-space) of the child, and (b) the information processing demands of the task must be known. This study addresses the problem of assessing information processing capacity.

According to Case (1978a), a test must possess the following four properties to qualify as a measure of M-space: (a) children must be presented a series of intellectual operations to execute, (b) additional information must be stored while these operations are executed, (c) means must be provided for incrementing the amount of information to be stored, and (d) means must exist for determining when a subject's storage capacity is exceeded. In addition, to insure that the number of external units of information counted by the experimenter corresponds with the number of internal units actually stored by the subject, several technical requirements must be met:

1. Sufficient pretraining must be presented to insure that no extra memory space is devoted to any extraneous requirement such as understanding the general requirements of the test, accessing the required operations, or recognizing the stimuli.

2. The test must be designed so that there is no possibility of using a sophisticated strategy which would reduce the processing requirements.

3. The items to be stored in the test must be designed so that they are not susceptible to any higher order chunking which might reduce the

storage demands.

Specifying the information demands of the task is difficult, because the information processing demands of the tasks must be analyzed from the child's point of view. As Case (1975) put it: "The natural units into which the learner analyzes the task should be considered more important than the a priori units into which a sophisticated instructor might divide them." This type of analysis is particularly demanding since different children have different schemes available in their cognitive repertoires and hence may approach problems in different ways. "Since M demand is defined from the subject's point of view, the same task may have different M demands for different subjects depending on the schemes they bring to the task and on how they chunk the information presented to them in the task" (Scardamalia, 1977).

Hiebert's Study

This study, carried out at the University of Wisconsin in 1979 examined the relationships of cognitive processing capacity, as measured by "backward digit span," on children's ability to learn measurement skills. Backward digit span as a measure of M-space did not effectively discriminate between those children who mastered the instructional skills and those who did not. Significant between-group differences in performance on the set of tasks were predicted. However, the results showed that, while there was variation in these scores, the factor of information processing capacity accounted for none of the variation. In fact, where significant between-group differences were found, they were in the "wrong" direction on a logically unrelated set of tasks. Low M-space children performed significantly better than high

M-space children on the technique-based measurement tasks. This result is difficult to explain. It may be that the technique put high M-space at a disadvantage. Certainly the results reinforce the nonproductive nature of the measure of M-space in Hiebert's study and the need to examine in greater depth the relationship of M-space and task requirement.

Thus, a basic problem encountered in applying the M-space notion to an instructional context is to identify an appropriate measure of M-space. Hiebert used the Backward Digit Span test which has been frequently used in the past (Case, 1974, 1977; Lawson, 1976; Parkinson, 1975). It should be a valid measure since it requires two abilities which make up the M-space construct: short-term memory and an information operation or transformation. The numbers in the task not only have to be held in mind, they have to be held in mind while operating on them in some way.

A fundamental question is whether a single general measure of M-space is appropriate. Recent work by Case and associates (Case, Kurland, and Daneman, Note 3) suggests that it may be very difficult to construct a general measure of M-space which will predict performance on a wide range of tasks. Their data indicate that task variables such as stimulus familiarity may be more important than previously supposed in determining the M-space demand of a particular task. Operational efficiency is suggested to be as critical as M-space in predicting performance on a given task. Since operational efficiency depends on task variables and on the subject's available schemes or mental processes, the ability to apply a certain processing capacity will change from context to context.

Clearly, the usefulness of M-space in educational contexts depends upon

the possibility of developing procedures to specify the M-demand of complex learning tasks and a single (or multiple) measure of M-space which would predict children's performance for a given set of tasks.

Case and Kurland's Study

Faced with a problem of the practical utility of M-space tests for children under the age of about six, Case and Kurland (1978) set out to construct and validate a new measure of M-space. The new test, called "The Counting Span Test," met the criteria stated earlier. The validation of the measure involved first a sample of six boys and six girls at each of four different age levels (4, 6, 8, and 10) were selected from a university laboratory school. Since the population was small, quite homogeneous with regard to I.Q. (100+), motivation (high), and social class (upper-middle), and was quite "test wise" the sample was less than ideal. Three tests, Counting Span, Mr. Cucui, and Digit Placement, were given. Although positive correlations (.5 to .6) were found the consistency between measures was not high.

Given the relatively small sample and the less than definitive results from Case's study, we decided to use in the present study the three tests Case and Kurland used along with Backward Digit Span from Hiebert's study to see if together they would yield an estimate of a child's memory capacity.

Procedures

The Tests

The Counting Span test. This test was the new instrument developed by Case and Kurland (1978). Conceptually, it is very straightforward. The operation required is counting. The items which must be stored are the products

of a series of counting operations. Children are presented with arrays of geometric shapes to count, and are asked to recall the number of objects in each array as soon as they have finished counting the whole set. The number of arrays in the set is incremented from trial to trial and subjects' M-space is assumed to be equal to the maximum number of arrays which they can count while maintaining perfect recall.

So that the task instructions, operations, and stimuli were familiar, subjects were presented with a number of pretraining trials before the actual testing began. To prevent higher order "chunking" of the numbers to be recalled, sequences employing consecutive numbers were avoided, as were sequences in which all the numbers were odd or even. Also, no number appeared twice in a given trial, or in the same position on two successive trials. Three controls were introduced to insure that no space-saving strategies were possible: First, a number of grey distractor shapes were included in the array of colored shapes to be counted. The purpose of the distractor shapes was to break up any visual patterns which might permit the subject to determine the number of shapes by subitizing. Second, subjects were required to touch each shape and to call out the numbers aloud. Third, the stimulus cards were presented in immediate succession with no intervening time for rehearsal.

The test includes 33 items. However, at most only five items were scored at any one of the five M-space levels. The test protocol, scoring sheets, sample sets and the specification of the sets employed in this test appear in Appendix A.

To reduce the total number of trials a modified "ceiling basal" method

was used (Bachelder and Denny, 1977). Children were presented with sets from different M-space levels until it was determined at what level they passed and at what level they failed. They were then presented with a larger number of trials until the level of complete success and the level of complete failure had been determined.

Mr. Cucui. This measure was designed in Pascual-Leone's laboratory by DeAvila, for use with children with an imperfect command on English (DeAvila and Havassy, 1974). The form used in the present study was developed by Case. It was quick to administer and suitable for use with four-year-olds as well as older children.

On each trial, children are presented with the outline of Mr. Cucui. After viewing it for 5 seconds, they are told to remember what parts of his body are colored. They are then presented with a blank outline drawing of Mr. Cucui, and told to point to the parts which were colored. There are twenty-five items, five different items at each of five levels, and a level is defined as the number of body parts which are colored.

This test is the only one which does not require the student to count or use numbers. Instead, recall of spatial location is required to respond correctly. The test protocol, scoring sheets, sample item, and specifications for the items appear in Appendix B. The same ceiling-basal method as was used in the Counting Span test was followed.

The Digit Placement test. This is a measure of M-space which was developed and standardized by Case. It is known to yield the same norms as other tests of M-space (cf. Case, 1972), and to load highly on the general factor defined by more lengthy M-tests such as Pascual-Leone's CSVI (Case & Globerson,

1974). The basic procedure is to present subjects with a set of n numbers. The first n-1 of these are in ascending order of magnitude (e.g., 2, 5, 9, 12), and the nth is out of order (e.g., 7). After the numbers have disappeared from view, the children are asked to indicate where the final number belongs in the original series. Subjects' M-space corresponds to the maximum set size for which they can execute the task successfully. For this test there are 15 items (five for each of three levels). Levels 1 and 5 are not tested. The test protocol, scoring sheets and items appear in Appendix C.

The Backward Digit Span test. The form used in this study was developed by Hiebert (1979). It has the property of being easy to administer. On each trial the experimenter states a series of digits. The subject is to repeat them in the reverse order. Subjects M-space correspond to the maximum set size to which they can respond successfully. In this test there are 40 items (10 at each of four levels). Level 1 is not tested. The test protocol, items and scoring sheets appear in Appendix D.

The Population

All of the children in Sandy Bay Infant School in Hobart, Tasmania constituted the sample for this study. The school is located on the Derwent River in Sandy Bay, a suburb of Hobart near the University of Tasmania. The community is middle to upper-middle class. The children's age range was from 4 years 9 months to 8 years 2 months. There were 74 boys and 68 girls (142 total) in six classrooms. The distribution of the 139 boys and girls who participated in the study is shown in Table 1. The six classes include

Table 1

Number of Boys and Girls in Each of the Six Classes

Class	1 K-AM	2 K-PM	3 Prep	4 Gr 1	5 Gr 1/2	6 Gr 2
Boys	16	11	8	8	15	15
Girls	9	9	13	14	9	12
Totals	25	20	21	22	24	27

two kindergarten classes,[1] one which met in the morning (K-AM) and one which met in the afternoon (K-PM), a prep class, a grade 1 class, a grade 2 class, and a combination grade 1/2 class. The age distributions for each class are shown in Table 2.

Test Administration

A research assistant and two experienced teachers were hired to administer the tests. All were trained before the testing proceeded. One assistant administered the Counting Span test, a second the Mr. Cucui test, and the third the Digit Placement and the Backward Digit Span tests. Children were randomly selected by their teacher to come to the interview room (the teachers' lounge). Each interviewer was in a corner of the room. Children were randomly assigned to an interviewer. Most children took two tests

[1] In Tasmania kindergarten corresponds with nursery school age while prep corresponds with the U.S. kindergarten.

Table 2

Range and Average Ages of Children in Each Class

Class	1 K-AM	2 K-PM	3 Prep	4 Gr 1	5 Gr 1/2	6 Gr 2
Youngest ages	4-9	5-0	5-4	6-2	6-5	7-3
Oldest ages	5-1	5-7	6-1	7-3	7-10	8-2
Average age	4-11	5-4	5-10	6-7	7-3	7-8

Note: 4-9 means 4 years 9 months as of Oct. 1, 1979, and so forth.

on one day and the other two a day or two after. All testing was completed within ten days. One child (age 4 years 10 months) was frightened of the interview procedure and asked not to be tested after the first test, and two children were sick after partial testing. Thus usable data on 139 subjects was collected.

Scoring the Tests

Although each item in each test can obviously be scored 1 or 0 (for correct or incorrect) and the number of items answered correctly can be counted, there are three problems in using this method to estimate each child's level of M-space. First, since sets of items in each test were designed to measure different levels of M-space, item scores must be weighted

to reflect those levels. Second, since the ceiling basal procedure was used with both the Counting Span test and the Mr. Cucui test some items were not actually administered to each child. To account for this, items not administered but at a level lower than where the child answered correctly were scored correct and all items at a level higher than where the child responded correctly were scored incorrect[2]. Third, the decision rules for indicating partial M-space level, as used by Case and Kurland and Hiebert, were considered questionable; for instance if 80% or more of the items correct at a level was used in all tests as the determining criteria, whether additional partial level points should be assigned for correct responses made at higher levels is unclear.

Four scoring rules were devised for each test. The first (S-1) was simply the number of items correct. The second (S-2) was a weighted score to estimate partial level. A partial score was only counted for one level. Any items correct at higher levels were not scored. The third (S-3) was a "absolute level" score in which the partial part of the S-2 was omitted. The final rule (S-4) was also an absolute-level score but was based on the total number of correct responses. A difference between S-3 and S-4 could indicate either a change in strategy (contrary to the theory) or a lack of scale reliability. S-4 is in fact more conservative than S-3 since all errors deduct from the total scores, even haphazard errors at early levels. Thus, the classification of some children by S-4 into lower levels than by S-3 was to be expected. However, if the S-4 classification was greater than

[2]For the Digit Placement test and the Backward Digit Span test <u>all</u> subjects were assumed to be at least at level 1.

that for S-3, a change in strategy could be indicated. A positive shift could only occur if a child started to get a significant number of items correct after he had made enough errors at a lower level for his absolute level (by rule S-3) to have been reached. The details of the scoring procedures for each test appear in Appendix E.

Relationship of Scores Generated by the Different Scoring Rules.

This section has been organized to illustrate the difference in results obtained by using each of the different scoring rules.

The Counting Span test. The distributions of scores for this test using each scoring rule are shown in Tables 3 to 6. The range of scores is from 3 to 22 correct. The average number of correct responses increases over grades (from 6.56 to 13.00). However, the overlap of scores by classes is striking. There are several kindergarteners who score as high or higher than second graders (see Table 3).

In Table 4 the number of children who respond correctly to 1, 2 or 3 items (but not 4 or 5) out of each set of five items which presumably measure a level is quite interesting. A partial score of .2, .4, or .6, as dictated by rule S-2, is added to the child's scores. The resulting distribution of partial scores indicates that the shift from one M-space level to another level is not as abrupt as the theory would indicate. Children are able to respond correctly to some items at higher levels than their absolute level score would indicate.

Table 5 simply collapses the partial score data in Table 4 to the implied basal M-space levels. Although the trend across classes is maintained, the overlap of children in all grades is still obvious.

Table 3

Frequency of Correct Responses (S-1) for Children in Each Class and for the Total Population for the Counting Span Test

Number correct	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	$\bar{X}$	SD
(1) K-AM			12	2	1	7	1	2													6.56	1.76
(2) K-PM	1	1	2	1	1	4	1	5		1	2	1									8.65	3.07
(3) Prep		1	6	1	1	2	5	3		1			1								7.86	2.80
(4) Gr 1					1	3	5	5	3	1	1	2	1								10.32	2.15
(5) Gr 1/2			1				2	1	3	2	7	3	4	1							12.46	2.17
(6) Gr 2						2	1	7		1	3	7	2			2	1			1	13.00	3.46
Totals	1	2	21	4	4	18	15	23	6	6	13	13	8	1		2	1			1	9.92	3.56

Table 4

Frequency of Scores Derived from Scoring Rule 2 (S-2) for Children in Each Class and for the Total Population for the Counting Span Test

Score	.6	1	1.2	1.4	1.6	2	2.2	2.4	2.6	3	3.2	3.4	3.6	4	$\bar{X}$	SD
(1) K-AM		12	2	1	7	2	1								1.33	.38
(2) K-PM	1	3	1	1	4	5	1		3	1					1.78	.64
(3) Prep		7	1	1	2	7	1	1			1				1.65	.61
(4) Gr 1				1	3	10	2	2	1	3					2.14	.45
(5) Gr 1/2			1			3	2	2	8	7	1				2.56	.46
(6) Gr 2				1	1	8		2	2	9			3	1	2.63	.67
Totals	1	22	5	5	17	35	7	7	14	20	2		3	1	2.03	.73

Table 5

Frequency of Scores Derived from Scoring Rule 3 (S-3) For Children in Each Class and for the Total Population for the Counting Span Test

Score	0	1	2	3	4	$\overline{X}$	SD
(1) K-AM		22	3			1.12	.33
(2) K-PM	1	9	9	1		1.50	.69
(3) Prep		11	9	1		1.52	.60
(4) Gr 1		4	15	3		1.96	.57
(5) Gr 1/2		1	15	8		2.29	.55
(6) Gr 2		2	12	12	1	2.44	.70
Total	1	49	63	25	1	1.83	.75

In Table 6 the implied M-space levels derived by scoring rule S-4 are shown. Differences in categorization of individuals between S-4 and S-3 are shown in Table 7. The 31 children who are categorized by S-4 into a lower M-space level reflect the more conservative scoring procedures than occur in S-3. In S-3 if 4 of 5 are correct in a category, a child is put in that category. Using S-4, this would not occur unless the child got at least one other item at a higher level correct. The reason for using S-4, however, was to identify those children who would be categorized at a higher M-space level by this rule than with S-3. This could occur if the child had reached

Table 6

Frequency of Scores Derived from Scoring Rule 4 (S-4) For Children in Each Class and for the Total Population for the Counting Span Test

Score	0	1	2	3	4	$\overline{X}$	SD
(1) K-AM		23	2			1.08	.28
(2) K-PM	2	9	9			1.35	.67
(3) Prep	1	15	4	1		1.24	.63
(4) Gr 1		9	12	1		1.64	.58
(5) Gr 1/2		3	16	5		2.08	.58
(6) Gr 2		3	18	5	1	2.15	.66
Totals	3	62	61	12	1	1.61	.71

Table 7

Distribution of Children Using Scoring Rules S-3 and S-4 for the Counting Span Test

Score S-4	0	1	2	3	4
Score S-3					
0	1				
1	2	47			
2		15	48		
3			13	11	1
4				1	

his M-space level and then changed strategies (chunked information) in order to correctly respond to higher level questions. However, for this test there was only one child whose scores exhibited this possibility.

The Mr. Cucui test. The distributions of scores for this test using each scoring rule are shown in Table 8 to 11. The range of scores is from 0 to 19 correct. As with the Counting Span test, although the average number of correct responses increases over grades (from 4.04 to 12.04) and although the overlap of scores by classes is apparent, there are several second graders who score in the range of kindergarteners (see Table 8).

In Table 9 the number of children who respond correctly to 1, 2 or 3 items out of each set of five items which presumably measure a level is quite high (a partial score of .2, .4, or .6 is added to the child's score). Again this distribution of partial scores indicates that the shift from M-space level to level is not as abrupt as the theory would indicate. Children are able to respond correctly to some items at higher levels than their absolute level score would indicate.

Table 10 simply collapses the partial score data in Table 9 to the implied basal M-space levels. Although the trend across classes is again maintained, the overlap of children across all grades still exists.

In Table 11 the implied M-space levels derived by scoring rule S-4 are shown. Differences in categorization of individuals between this scoring rule S-4 and S-3 are shown in Table 12. There are 33 children who are categorized by S-4 into a lower M-space level. This reflects the more conservative scoring than occurs within S-3. There are five children categorized at a higher M-space level by S-4 than by S-3. This could occur if the child

Table 8

Frequency of Correct Responses (S-1) for Children in Each Class and

for the Total Population for the Mr. Cucui Test

Number correct	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	$\bar{X}$	SD
(1) K-AM	2	1	3	6	6	1	2	1		2	1										4.04	2.61
(2) K-PM	2		2	1	3	4	1	1	2	2	1		1								5.40	3.25
(3) Prep		1		3	3	5		2	2	1	3		1								6.10	2.93
(4) Gr 1		1			3	3	2			2	3	2			1	3	1	1			9.18	4.69
(5) Gr 1/2					1	1	1	2	1	2	2	2	1	2	1	2	2	1	1	2	11.83	4.46
(6) Gr 2				1	3				1	3	3	1	1		3	5	1	3		2	12.04	4.70
Total	4	3	5	11	19	14	6	6	6	12	13	5	4	2	5	10	4	5	1	2	8.53	5.00

Table 9

Frequency of Scores Derived from Scoring Rule 2 (S-2) for Children in Each Class and for the Total Population for the Mr. Cucui Test

Score	1	1.2	1.4	1.6	2	2.2	2.4	2.6	3	3.2	3.4	3.6	4	4.2	4.4	4.6	5	$\bar{X}$	SD
(1) K-AM	2	1	4	5	6	2	2	2	1									1.85	.52
(2) K-PM	2		2	3	3	2	3	3	1		1							2.07	.64
(3) Prep		1		3	4	4	2	2	3		2							2.31	.60
(4) Gr 1		1			5	2	1	1	3	3		2	1	1	2			2.88	.90
(5) Gr 1/2					2	1	2	1	2	3	1	3	2	3	1	1	2	3.46	.90
(6) Gr 2				1	3		1	2	5		1	1	4	3	4		2	3.46	.97
Totals	4	3	6	12	23	11	11	11	15	6	5	6	7	7	7	1	4	2.71.	1.01

Table 10

Frequency of Scores Derived from Scoring Rule 3 (S-3) for Children in Each Class and for the Total Population for the Mr. Cucui Test

Score	1	2	3	4	5	$\overline{X}$	SD
(1) K-AM	12	12	1			1.56	.58
(2) K-PM	5	11	2			1.75	.64
(3) Prep	4	12	5			2.05	.67
(4) Gr 1	1	9	8	4		2.68	.84
(5) Gr 1/2		6	9	7	2	3.21	.93
(6) Gr 2	1	6	7	11	2	3.26	1.02
Totals	25	56	32	22	4	2.45	1.05

Table 11

Frequency of Scores Derived from Scoring Rule 4 (S-4) for Children in Each Class and for the Total Population for the Mr. Cucui Test

Score	1	2	3	4	$\overline{X}$	SD
(1) K-AM	18	6	1		1.32	.56
(2) K-PM	8	10	2		1.70	.66
(3) Prep	7	10	4		1.86	.73
(4) Gr 1	4	7	6	5	2.56	1.06
(5) Gr 1/2	1	7	8	8	2.96	.91
(6) Gr 2	4	4	8	11	2.96	1.09
Totals	42	44	29	24	2.25	1.07

Table 12

Distribution of Children Using Scoring Rules S-3 and S-4 for the Mr. Cucui Test

Scores S-4	1	2	3	4	5
Score S-3					
1	25				
2	17	36	3		
3		8	22	2	
4			4	18	
5				4	

had changed strategies (chunked information) in order to correctly respond to higher level questions.

The Digit Placement test. The distributions of scores for this test using each scoring rule are shown in Tables 13 to 16. The range of scores is from 0-15 correct. As with the previous tests although the average number of correct responses increases over grades (from 1.24 to 12.63) the overlap of total scores is considerable. However, the large number of children (42) who got no items correct, particularly kindergarteners, reflects the difficulty of this test (see Table 13). Many of the youngest children simply could not understand what was wanted.

In Table 14 the number of children who respond correctly to 1, 2, or 3 items out of each set of five which presumably measure a level and are scored in a manner similar to the previous tests is shown. This distribution of partial scores again indicates that the shift from M-space level to level is not as abrupt as the theory would indicate.

Table 15 collapses the partial score data in Table 4 to the implied basal M-space levels. Note that in both Tables 14 and 15 even though many children could not answer any items correctly they were labeled "level 1" since there were no "level 0" items. Again, although the trend across classes is apparent, the overlap of children in all grades is striking.

In Table 16 the implied M-space levels derived by scoring rule S-4 are shown. Differences in categorization of individuals between scoring rule S-4 and S-3 are shown in Table 7. Sixteen children are categorized by S-4 into a lower M-space level which again reflects the more conservative scoring than occurs in S-3. Children categorized at a higher M-space level by this

Table 13

Frequency of Correct Responses (S-1) for Children in Each Class and for the Total Population for the Digit Placement Test

Number correct	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	$\bar{X}$	SD
(1) K-AM	16	3	2	1	1		1					1					1.24	2.54
(2) K-PM	10	5	2		2						1						1.35	2.39
(3) Prep	6	3	4	1	1	2	1			1	1	1					3.05	3.44
(4) Gr 1	6	2		3	1	2		4	2	1		1					4.05	3.53
(5) Gr 1/2	3			1			3		1	2	1	4	1	3	3	2	9.33	4.78
(6) Gr 2	1										2		4	4	7	7	12.63	3.13
Totals	42	13	8	6	5	4	5	4	3	6	5	7	5	7	10	9	5.58	5.54

Table 14

Frequency of Scores Derived from Scoring Rule 2 (S-2) for Children in Each Class and for the Total Population for the Digit Placement Test

Score	1	1.2	1.4	1.6	2	2.2	2.4	2.6	3	3.2	3.4	3.6	4	$\overline{X}$	SD
(1) K-AM	16	4	4									1		1.20	.52
(2) K-PM	10	5	4	1										1.16	.19
(3) Prep	6	6	4	3		1		1						1.35	.41
(4) Gr 1	6	2	7	3			1	2				1		1.56	.67
(5) Gr 1/2	3		2	7		2	1	3					6	2.32	1.10
(6) Gr 2	1			4				1				2	19	3.45	1.00
Totals	42	17	21	18		3	2	7				4	25	1.90	1.13

Table 15

Frequency of Scores Derived from Scoring Rule 3(S-3) for Children in Each Class and for the Total Population for the Digit Placement Test

Score	1	2	3	4	$\overline{X}$	SD
(1) K-AM	24		1		1.08	.40
(2) K-PM	20				1.00	.00
(3) Prep	19	2			1.10	.30
(4) Gr 1	18	3	1		1.23	.53
(5) Gr 1/2	12	6		6	2.00	1.25
(6) Gr 2	5	1	2	19	3.30	1.20
Totals	98	12	4	25	1.68	1.17

Table 16

Frequency of Scores Derived from Scoring Rule 4 (S-4) for Children in Each Class and for the Total Population for the Digit Placement Test

Score	1	2	3	4	$\bar{X}$	SD
(1) K-AM	23	1	1		1.12	.44
(2) K-PM	19		1		1.10	.45
(3) Prep	15	4	2		1.38	.67
(4) Gr 1	12	9	1		1.50	.60
(5) Gr 1/2	4	7	11	2	2.46	.88
(6) Gr 2	1	3	16	7	3.07	.73
Totals	74	24	32	9	1.83	1.00

Table 17

Distribution of Children Using Scoring Rules S-3 and S-4 for the Digit Placement Test

Score S-4	1	2	3	4
Score S-3				
1	74	15	9	
2		9	3	
3			4	
4			16	9

rule than by S-3 may have changed strategies during the test. For this test there are 27 such children.

It was noticed during administration of this instrument that several children missed items and then seemed to catch on and answered many items correctly. After reviewing the response sheets, we concluded that this effect was not due to change in strategy. After attempting and making errors on the first few items these children finally understood the directions and started to respond correctly to new items. The instructions, although the same for every item, were repeated each time (twice if missed although at no time was the child told his response was correct or not). Confusion over the instructions was apparent for many children. Item administration was terminated only after three consecutive items had been missed and the children's level was fixed. Thus, each child would have heard the instructions at least six times. These children simply caught on to the task. In view of this, we decided for this test only to record both the S-3 and the S-4 levels for each child and examine each set of effects separately in subsequent analysis.

The Backward Digit Span test. The distributions of scores for this test using each scoring rule are shown in Tables 18-21. The range of scores is from 0-30 correct. As Table 18 shows, the average number of correct responses increases over grades (from 7.00 to 13.58), as with the other tests.

In Table 19 the number of children who respond correctly to one to six items out of each set of 10 items which presumably measure a level is still striking. In these cases a partial score of .1, .2, etc. is added to the child's score. As with the other tests this distribution of partial scores indicates that the shift from M-space level to level is not as abrupt as the

Table 18

Frequency of Correct Responses (S-1) for Children in Each Class and for the Total

Population for the Backward Digit Span Test

Number correct	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	$\bar{X}$	SD
(1) K-AM	5		1	2	1	1	2	1			7	1		1	1	1	1															7.00	5.11
(2) K-PM	1	1							1	1	9	2	2	1	2																	9.75	3.52
(3) Prep								1		1	3	3	6	1		1	2	2				1										12.67	3.26
(4) Gr 1											3	6	2	2	1	2	1	1	2		1			1								13.73	3.62
(5) Gr 1/2												1	2	1	5	1	2	2	3	5		1	1									16.29	2.49
(6) Gr 2												2		1			1	1	1	2	9	1	3				1	2	1	1	1	20.67	4.89
Totals	6	1	1	2	1	1	2	2	1	2	22	15	12	7	9	5	7	6	6	7	10	3	4	1			1	2	1	1	1	13.58	6.08

Table 19

Frequency of Scores Derived From Scoring Rule 2 (S-2) for Children in Each Class and for the Total Population for the Backward Digit Span Test

Score	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	3	3.1	3.2	3.3	3.4	3.5	3.7	4	4.1	$\bar{X}$	SD
(1) K-AM	5		1	2	1	1	2	1	7	1			2	1	1											1.70	.52
(2) K-PM	1	1							11	1	2	2	2													2.00	.36
(3) Prep								1	4	3	5	2		1	3	2										2.25	.27
(4) Gr 1									2	6	3	2	1	2	2		3			1						2.30	.38
(5) Gr 1/2										1	2	1	4	2	4	2	3	4	1							2.66	.34
(6) Gr 2										2		1		1		4	6	2	4	1			2	3	1	3.10	.55
Totals	6	1	1	2	1	1	2	2	24	14	12	8	9	7	10	8	12	6	5	2			2	3	1	2.37	.63

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theory would indicate. In fact, for all of the tests the shift from M-space level to level appears to be on a continuum rather than in discrete jumps.

Table 20 collapses the partial score in Table 4 to the implied basal M-space levels.

Table 20

Frequency of Scores Derived from Scoring Rule 3 (S-3) for Children in Each Class and for the Total Population for the Backward Digit Span Test

Score	1	2	3	4	$\overline{X}$	SD
(1) K-AM	13	12			1.48	.51
(2) K-PM	2	18			1.90	.31
(3) Prep	1	20			1.95	.22
(4) Gr 1		18	4		2.18	.40
(5) Gr 1/2		16	8		2.33	.48
(6) Gr 2		8	15	4	2.85	.66
Totals	16	92	27	4	2.14	.64

In Table 21 the implied M-space levels derived by scoring rule S-4 are shown. Differences in categorization of individuals between scoring rule S-4 and S-3 are shown in Table 7. Sixteen children were categorized by S-4 into a lower M-space level. This again reflects the more conservative scoring than occur using S-3. In S-3 if seven or more items are correct

Table 21

Frequency of Scores Derived from Scoring Rule 4 (S-4) for Children in Each Class and for the Total Population for the Backward Digit Span Test

Score	1	2	3	4	$\overline{X}$	SD
(1) K-AM	13	12			1.48	.51
(2) K-PM	4	16			1.80	.41
(3) Prep	2	18	1		1.95	.38
(4) Gr 1		20	2		2.09	.29
(5) Gr 1/2		22	2		2.08	.28
(6) Gr 2		8	18	1	2.71	.53
Totals	19	96	23	1	2.04	.58

Table 22

Distribution of Children using Scoring Rules S-3 and S-4 for the Backward Digit Span Test

Score S-4	1	2	3	4
Score S-3				
1	16			
2	3	86	3	
3		10	17	
4			3	1

in a category, a child is put in that category. For the same child that would occur using S-4 unless the child got at least as many other items correct at a higher level correct as he had missed in that category. For those three children categorized at a higher M-space level by S-4 than by S-3, the data again indicate they had changed strategies (chunked information) in order to correctly respond to higher level questions.

Summary. The distributions for the four memory tests using the four different scoring rules provide interesting results. First, as children increase in age, scores generally increase. However, the overlap of scores among children at different grade levels is quite striking. Clearly, scores are related to age but not specifically determined by age.

Second, scoring rule S-1, which gives the number of correct answers, indicates there were problems with the Digit Placement test. This test should not be used with kindergarten children, many of whom were unable to respond correctly to a single item. Digit Placement is simply unreliable as a measure of memory space for children of that age. The other three tests, on the other hand, can be used for children of kindergarten age.

Third, the predominance of partial level scores for children on each test indicates that there is no abrupt shift or change in M-space level.

Fourth, the variation of scores across tests could imply that the context of the test may give students a cue which helps them answer questions above their M-space level as indicated by another test.

Finally, the data from scoring rule S-4 on tests 1, 2, and 3 shows that few children appear to incorporate a strategy of chunking information so that they could solve problems beyond the memory space level indicated.

These children need to be isolated and followed up in a further study and their strategies analyzed thoroughly. Such a study might give clues as to how M-space levels change. However, the positive shift in the Digit Placement test would seem to be due to an initial failure to understand the instructions (see p. 4). This was apparent during administration of the test and the data show that some children after struggling with several low level items finally understood the task and began to solve higher level items. Further study is warranted to see if pre-training on a similar task makes this a viable instrument. The distribution by class of children whose scores using S-4 were higher than S-3 for the four tests is shown in Table 23.

Table 23

Distribution by Class and Test of Children With a Higher M-space Level Using S-4 Rather Than S-3

Test	CS	MC		DP			BDS	
Shift levels	3-4	2-3	3-4	1-2	1-3	2-3	2-3	Totals
K-AM				1		1		2
K-PM		1[a]			1[a]	1		3(2)
Prep				2	2[a]	1	1[a]	6(5)
Gr 1		1	1[a]	6[a]				8(7)
Gr 1/2				4	4			8
Gr 2	1	1	1	2	2		2	9
Totals	1	3	2	15	9	3	3	36[b]

[a] Same child

[b] 33 children

It should be noted that 24 of the 27 positive shifts on the Digit Placement test were from level 1 upward. Since level 1 meant 2 or more of the first 5 items were missed, this confirms the belief that these children only gradually understood the task.

Thirty-three children exhibited 36 instances of a positive shift in M-space level by using scoring rule S-4 rather than S-3 across the tests. The number of positive shift goes up with age. However, the importance of these shifts is not yet clear.

Relationship of Scores on the Four Memory Tests.

If the memory tests are valid, the classification of individual children into level of M-space should be the same regardless of the context. The items in each of the four tests administered in this study present children with different contexts. The items require children to organize and solve problems. The tasks should reflect the amount of processing capacity available to the children. Because the student population covers a wide age range and varied widely in performance, we must question whether the tests yield similar classifications of children. First, the scores from the four tests on the total population were correlated. Second, the data for all pairs of tests were cross tabulated to see how many classifications were the same. Third, a factor analysis was performed to determine the dimensionality of the M-space correlation. Finally, a cluster analysis was done to group children.

Correlations of test scores. The correlation of the test scores for the four memory tests using scoring rule S-3 for the total population appears in Table 24. The correlations, while all positive, are not particularly high. The highest is only .59. The correlations of these four tests for the whole population, but using the S-4 score for the Digit Placement test for the 27

Table 24

Correlations of Scores for the Four Memory Tests Using Scoring Rule S-3 for the Total Population

	CS	MC	DP	BDS
Counting Span (CS)	1.00			
Mr. Cucui (MC)	.50	1.00		
Digit Placement (DP)	.56	.38	1.00	
Backward Digit Span (BDS)	.52	.40	.59	1.00

positive shift cases only, were also calculated. These correlates are not much different from the correlations in Table 25. Although the Digit Placement scores now correlate a little higher with the scores of the other tests, these low correlations could have been due to truncation of the distribution

Table 25

Correlations of Scores for the Four Memory Tests Using an Adjusted Scoring Rule for the Digit Placement Test for the Total Population

	CS	MC	DP	BDS
Counting Span (CS)	1.00			
Mr. Cucui (MC)	.49	1.00		
Digit Placement (DP)	.61	.50	1.00	
Backward Digit Span (BDS)	.52	.40	.64	1.00

which resulted from disregarding partial scores. Thus, correlations for the four memory tests using scoring rule S-2, which uses partial scores, also were calculated (see Table 26). While these correlations are a little higher the largest is only .66.

Table 26

Correlations of Scores for the Four Memory Tests Using Scoring Rule S-2 for the Total Population

	CS	MC	DP	BDS
Counting Span (CS)	1.00			
Mr. Cucui (MC)	.55	1.00		
Digit Placement (DP)	.57	.43	1.00	
Backward Digit Span (BDS)	.63	.46	.66	1.00

Although these tests are positively correlated, the correlations are not high and on this evidence one may conclude that the substitution of one test for another will not necessarily classify children into the same M-space levels.

Cross tabulations of scores for the four tests. To examine the similarity between classification schemes based on the four tests we cross tabulated the data for each test with each other test. The classifications have all been done first using S-3 which puts each child into a basal M-space level, and then repeated using adjusted Digit Placement scores.

Tables 27-32 show these pairwise classifications. In each pairwise comparison

Table 27

Number of Children Classified into "M-space" Levels by the Counting Span Test and the Digit Placement Test (with Adjusted Digit Placement Levels)

Digit Placement	1	2	3	4
Counting Span				
0	1			
1	45	3	1	
2	45	7	3	8
3	7	2		16
4				1

Digit Placement (adjusted)	1	2	3	4
Counting Span				
0	1			
1	40	7	2	
2	30	14	11	8
3	3	3	3	16
4				1

Table 28

Number of Children Classified into "M-space" Levels by the Counting Span Test and the Mr. Cucui Test

Mr. Cucui	1	2	3	4	5
Counting Span					
0	1				
1	15	26	7	1	
2	9	23	17	13	1
3		7	8	7	3
4				1	

Table 29

Number of Children Classified into "M-space" Levels by the Counting Span Test and the Backward Digit Span Test

Backward Digit Span	1	2	3	4
Counting Span				
0		1		
1	14	33	2	
2	2	48	11	2
3		10	13	2
4			1	

Table 30

Number of Children Classified into "M-space" Levels by the Digit Placement Test and the Mr. Cucui Test (with Adjusted Digit Placement Levels)

Mr. Cucui	1	2	3	4	5
Digit Placement					
1	24	42	22	9	1
2		7	1	3	1
3		1	2	1	
4	1	6	7	9	2

Mr. Cucui	1	2	3	4	5
Digit Placement (adjusted)					
1	23	34	13	3	1
2	1	12	7	4	
3		4	5	6	1
4	1	6	7	9	2

Table 31

Number of Children Classified into "M-space" Levels by the Digit Placement Test and the Backward Digit Span Test (with Adjusted Digit Placement Levels)

Backward Digit Span	1	2	3	4
Digit Placement				
1	16	76	6	
2		6	6	
3		3	1	
4		7	14	4

Backward Digit Span	1	2	3	4
Digit Placement (adjusted)				
1	16	57	1	
2		18	6	
3		10	6	
4		7	14	4

Table 32

Number of Children Classified into "M-space" Levels by the

Mr. Cucui Test and the Backward Digit Span Test

Backward Digit Span	1	2	3	4
Mr. Cucui				
1	8	16		1
2	8	39	9	
3		23	8	1
4		12	8	2
5		2	2	

there are a number of children classified into the same categories using different tests. The proportion of students who are classified into the same categories and into different categories in each comparison is shown in Table 33. The percentage of individuals who are differently classified in the comparisons range from 81% to 25%. There is a little better agreement in the classification of students when the adjusted Digit Placement scores are used rather than the original scores.

This cross tabulation clearly demonstrates that the tests classify children in different ways. If these different classifications are along a single dimension, this is not a serious problem. It only means then each test identifies different breaking points on that dimension. However, if these tests are found to measure more than one dimension, they measure different things.

Table 33

Number of Classifications and Percentages of Classifications Which are the Same, Higher for the First Test and Lower for the First Test for all Test Comparisons

A/B	CS/DP	(CS/DPA)	CS/MC	CS/BDS	DP/MC	(DPA/MC)	DP/BDS	(DPA/BDS)	MC/BDS
Same A=B	53	58	47	75	42	49	27	44	57
%	38	42	34	54	30	35	19	32	41
Higher A>B	54	36	16	13	15	19	24	31	55
%	39	26	12	9	11	14	17	22	40
Lower A<B	32	45	76	51	82	71	88	64	27
%	23	32	55	37	59	51	63	46	19

Note: CS = Counting Span test.
DP = Digit Placement test.
DPA = Digit Placement test with adjustment.
MC = Mr. Cucui test.
BDS = Backward Digit Span test.

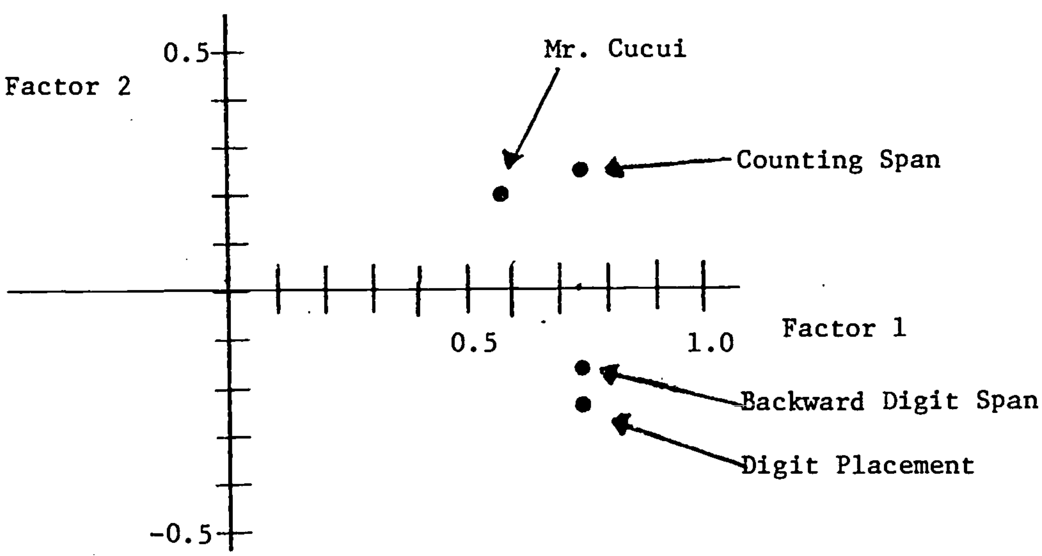
Factor analyses. To examine this dimensional question a factor analysis was performed on the correlation matrix presented in Table 2 for the four tests across the total population. The model used was a multifactor solution model. All extractions were principal factor extractions with iteration estimates of commonalities, and the varimax rotation procedure was used. The data for this factor analysis appears in Table 34. A two factor

Table 34

Factor Analysis for the Four Memory Tests Scored by S-3 for the Total Population

	Factors	
	1	2
Eigenvalues	2.05	.17
Raw Factor Matrix		
Counting Span	.76	.26
Digit Placement	.76	-.22
Mr. Cucui	.59	.17
Backward Digit Span	.73	-.16
Rotated Factor Matrix		
Counting Span	.46	.63
Digit Placement	.71	.35
Mr. Cucui	.27	.59
Backward Digit Span	.65	.37
% Variance	30.2	25.1

solution was derived although the Eigenvalue for the first factor is considerably larger than for the second factor. Plotting the data from the raw factor matrix indicates that the second dimension separates Mr. Cucui and the Counting Span tests from the Digit Placement and the Backward Digit Span tests. This possibly is due to a perceptual factor (see Figure 1). However, inspite of the existence of this second dimension, the first factor is by far the most important.



(values from Table 34)

Figure 1. Location of the four memory tests on the two dimensions of the factor analyses in Table 34.

A similar factor analysis was carried out for the correlation matrix which appears in Table 25. In this case a single factor was extracted (see Table 35). However, it should be noted that Mr. Cucui test did not

Table 35

Factor Analysis for the Four Memory Tests Scored by S-3 for the Total Population (with Adjusted Digit Placement Levels)

	Factor
	1
Eigenvalue	2.59
Raw Factor Matrix	
Counting Span	0.56
Digit Placement	0.72
Mr. Cucui	0.37
Backward Digit Span	0.51
% Variance	64.8

load heavily on this single factor. In both factor solutions a considerable amount of the variance is still unaccounted for. In both cases the remaining variance is due to the unique contributions of each test.

In summary, the four tests measure one primary factor, quantitative M-space. A second possible factor is suggested, perceptual capacity. The possibility of classifying a child into a category using only one of these

tests is due to the common quantitative factor which underlies all four tests, perceptual capacity as indicated by the unique contribution of that test. Thus, to classify children into M-space levels it would be best to administer a combination of tests as was done in this study and then classify the children with regard to that underlying structure. No one test is adequate to classify individuals into an M-space level, however. The next section indicates that a classification made on the basis of the results of perhaps three tests should be fairly reliable for most individuals. Thus the procedure is a useful research tool.

Cluster analysis. To classify the children in this population along a single dimension a cluster analysis procedure was used. The procedure uses Euclidean distances between points. The usual Euclidean distance points in four dimensions was used: $d = \sqrt{(x_1-y_1)^2 + (x_2-y_2)^2 + (x_3-y_3)^2 + (x_4-y_4)^2}$. A distance of zero indicate the points are identical. An examination of the 139 data cases in this study shows there are 49 separate patterns of responses. After consideration of the zero distances the cluster analysis then turns to distances equal to 1. The pattern of responses between individual sets of data differ by not more than 1 in the four dimensional space. For example, given a score of 1, 1, 1, 1 and a score of 2, 1, 1, 1, the distance between those points equals 1. ($d = \sqrt{1^2 + 0^2 + 0^2 + 0^2}$). The second step then groups the 49 data points into 28 sets. Arbitrarily we decided to cluster scores up to $d = \sqrt{2}$.

In Table 36 the estimated group vectors for the five groups so determined are given. One hundred and thirty six of the 139 children are included in these groups. The three individuals who were ungrouped had score vectors

Table 36

Estimated Vectors for the Five Groups Derived from a Cluster Analysis Where the Distance Between Score Vectors is Less than $\sqrt{2}$.

Group	Amalgamated distance	Number of children	Test (weights)			
			CS	DP	MC	BDS
1	1.27	72	1.44	1.13	1.68	1.82
2	1.37	37	1.97	1.11	3.35	2.22
3	1.23	7	2.14	3.71	3.57	2.00
4	1.03	11	2.91	4.00	2.46	2.91
5	1.41	9	2.78	3.89	4.11	3.22

of (0112), (3253), and (1234). The first child probably belongs in Group 1. This child was the only one to score 0 on the Counting Span test. If this is measurement error, the child would be in Group 1. The score vectors of the other two children, however, are decidedly different from any other score vector. These children will not be considered in any further work in the study.

The distribution of children in these five groups by class is shown in Table 37. This table clearly indicates that the groups with higher score vectors only appear in grades 1, 1/2, and 2 while the kindergarteners and preps are predominantly in Group 1.

Finally, because the differences between group basal vectors for Groups 2 and 3 were on the Digit Placement test and because most of the instances of children showing a positive shift in M-space level using scoring rule S-4

Table 37

Distribution of Children in Groups 1-5 by Class

Group	1	2	3	4	5	Other
K-AM	24	1				
K-PM	16	3				1
Prep	16	5				
Gr 1	10	11	1			
Gr 1/2	4	13	2	4		1
Gr 2	2	4	4	7	9	1
Totals	72	37	7	11	9	3

occurred on that test we decided to examine in what group the 33 children belonged. That information appears in Table 38.

As suspected the largest group of children were in Group 2 and all 17 of them had a positive shift on the Digit Placement test. These children would probably be classified in Group 3 rather than Group 2 if their S-4 level on the Digit Placement test was used rather than their S-3 level. Since it is not clear what effect this reclassification would have on the grouping of children a second cluster analysis using the adjusted Digit Placement scores was performed. In Table 39 the estimated group vectors for six groups now determined are shown. For this analysis an amalgamated distance of 1.45 was chosen rather than $\sqrt{2}$ (1.41) because the next two clusterings (after $\sqrt{2}$) yielded two groups similar to Groups 2 and 3 in the

Table 38

Distribution of the 33 Children with a Shift in Scores by the Groups Defined by Cluster Analysis

Group	1	2	3	4	5	Other
Shift						
CS(3-4)					1	
MC(2-3)	2			1		
(3-4)		1		1		
DF(1-2	6	9				
(1-3)	3	6				
(2-3)		2				1
BDS(2-3)	1		2			
Totals	12(10)[a]	18(17)	2	2	1	1

[a]The first number is number of shifts, the second number of children since some children would shift on more than one test.

previous analysis. The actual difference in distributions of the children to groups for the two analyses is shown in Table 40. The 27 children who had their Digit Placement scores adjusted and how they were classified is also shown in Table 40. Of the nine children in Group 1 whose scores were adjusted two remained in Group 1 and seven shifted to Group 2; of the 17 children in Group 2 whose scores were adjusted seven remained in Group 2, nine shifted to Group 3 and one was now not in any group; and the one child

Table 39

Estimated Vector for the Five Groups Derived from a Cluster Analysis where the Distance Between Scores Vectors is Less than 1.50 (with Adjusted Digit Placement Scores)

Group	Amalgamated distance	Number of children	Test			
			CS	DP	MC	BDS
1	1.05	59	1.32	1.07	1.61	1.73
2	1.44	38	1.90	1.66	2.76	2.13
3	1.43	16	2.25	2.10	3.69	2.25
4	1.03	11	2.91	4.00	2.46	2.91
5	1.06	4	3.17	3.83	4.50	2.67
6	1.23	6	2.50	4.00	3.75	3.75

who was previously not in a group now is a member of Group 6. Other children whose scores had not been adjusted remained in their original groups except that six Group 1 children were now in Group 2. What had been Group 5 was now split into two groups, two children who were in Group 2 now were in no group, and two children switched places from Groups 3 and 5. The changes appear reasonable in light of the adjusted scores. The major changes were in Groups 2 and 3 as anticipated and affected the group vectors, resulting in a readjustment of individuals in those groups. Why Group 5 split into two groups was only clear after re-examining the two analyses. In the first analysis Group 5 was formed from two groups at the last amalgamation step

Table 40

Common Grouping of Students from the Two Cluster Analyses

(Table 36 and 39)

Initial grouping and second grouping		1	2	3	4	5	Other
		72(9)[a]	37(17)	7	11	9	3(1)
1	59	59(2)	0	0	0	0	0
2	38	130(7)	25(7)	0	0	0	0
3	16	0	9(9)	6	0	1	0
4	11	0	0	0	11	0	0
5	4	0	0	0	0	4	0
6	6	0	0	1		4	1(1)
Other	5	0	3(1)	0	0	0	2

[a]Numbers in parentheses indicate those in each initial group whose score had been adjusted

(distance 1.45). In the second analysis, with nine new Group 3 students and a new Group 6 child, this amalgamation did not occur until 1.630 which was beyond the chosen cutoff. It should be noted that in both analyses all four of the last groups (3, 4, 5 and 6) clustered together (at distance 1.630 in the second analysis) before Group 1 and 2 amalgamated or before any of them clustered with the first two groups. This suggests that Groups 1 and 2 are distinct and that Groups 3, 4, 5, and 6, while different from

each other, are related at a general level different from the first two groups.

Group 1 is the largest group (59 members). The levels for this group are: CS - level 1, and DPT - level 1, BDS - level 1+, and MC - level 1. This group is clearly at M-space level 1. Children here are at the lowest level of cognitive development. Only for Backward Digit Span would the typical child be placed at level 2, and then only marginally (the group estimated value is 1.73).

Group 2 has 38 members. The levels for this group are: CS - level 2, MC - level 2+, BDS - level 2, and DPT - level 1+. These children exhibit a basic M-space level 2. They are below that level on the Digit Placement test, and nearly reach level 3 on the Mr. Cucui test. These differences we believe are due to factors extraneous to the test contexts: in the first case, understanding the complex instructions and in the latter case, spatial perception.

Group 3 with 16 members exhibits scores slightly above level 2 on three tests but nearly reach level 4 on the Mr. Cucui test. Their spatial perception is quite high but they still exhibit a basic M-space level of 2. We have labeled this group level 2S+ to highlight the fact these children are about that level spatially.

Group 4 has 11 members. These children exhibit different M-space levels depending upon the test. On two tests, Counting Span and Backward Digit Span, children are at level 3; on the Digit Placement test they are at level 4, but on the Mr. Cucui tests they are only at level 2. Their basic M-space level is level 3. Only the spatial perception involved in MC is not highly developed. Therefore we will label them <u>3S</u>-.

Group 5 has only 4 members, who have a similar pattern of levels to those in Group 4 except they score very high on Mr. Cucui. Their basic pattern is still at M-space level 3, and therefore we have labeled them 3S+.

Group 6 has 6 members. They are at M-space level 4. They are at that level on three tests but score below level 3 on Counting Span. It is not clear what the discrepancy on this test implies, but since this group is lower than Group 5 on both the Mr. Cucui and Counting Span tests it suggests that their spatial development is not yet to level 4 although their quantitative skills are at level 4. Therefore we have labeled them 4S-.

Overall these results reflect the two factors being measured by these tests. This suggests that we have unearthed an underlying cognitive mechanism. The contextual setting, number or space orientation, (quantitative or qualitative) has a significant effect on the child's ability to respond on any given occasion. This shows possible significant problem solving strategy/instruction reception differences between groups with the same basic cognitive processing potential. Spatial development (qualitative) and number development (quantitative) appear to be interwoven and occur close together in time, but some groups achieve number skill prior to spatial skill and others vice versa. The next study we designed looked at the relationship of M-space level to quantitative processing skills, so these results suggest a further study of spatial (qualitative) processing skills is also in order.

Conclusions

The specific purpose of this first study was to identify the working memory capacity (M-space level) of children of ages 4-8. From data gathered with tests purported to assess M-space we expected to group the children into

well defined sets with similar working memory capacities. The principal conclusion of this study is that with some qualifications this can be done. Groups of students can certainly be formed from the results of a set of tests. Using cluster analysis identifiable groups of students with similar patterns of responses to the set of tests may be formed. However, only an operational definition can be used to describe the actual capacity for each of the groups. The categories are not well defined in terms of M-space level.

The rationale for giving a set of different tests purporting to measure the construct of M-space is based on the results of two earlier studies, Hiebert (1979) and Case and Kurland (1978). The results of these studies suggested that it is difficult to construct a single measure of M-space which predicts performance on a wide range of tasks. Specific task variables, such as stimulus familiarity, maybe more important than previously supposed in determining the M-space demand of a particular task.

From the data in this study the variation of scores of across tests clearly indicates that the context of the tests gives student cues which helps them answer questions. Using three different scoring rules for each test we found that: (a) age is related to an increase M-space capacity, but M-space level is not determined by age, (b) the Digit Placement test is very difficult for young children and should not be used with kindergarten children, (c) partial level scores for children on each of the tests substantiates the importance of test context and demonstrates that there is no abrupt change in M-space level, and (d) using scoring rule S-4 we were able to identify very few children who seem to incorporate a strategy to "chunk" information.

Only on the Digit Placement test were there a large number of positive shifts. We decided, however, these shifts were due to gradually understanding the directions and were not a strategy shift.

The correlations of test scores on the four memory tests were all positive and significant but not high. Cross tabulations of the four tests indicated that children classified into an M-space level by one test would not necessarily be classified into the same level using another test. The amount of agreement of classification across tests varied from 19% to 54% of the cross classifications. In general, the Mr. Cucui test was the easiest of the tests (children were more often placed into higher M-space levels by that test than by the other tests) and Digit Placement separated children only into a low category or a high category.

Factor analysis of the original correlation matrix yielded two factors. The first factor was the primary factor. Factor analysis of the correlation matrix using adjusted scores yielded only one factor.

To classify children into unique groups a cluster analysis was performed, forming six groups. The largest group clearly has a M-space level of 1. Groups 2 and 3 are at M-space level 2 but differ in terms of their scores on the Mr. Cucui test. This indicates a difference in spatial perception. Groups 4 and 5 are at M-space level 3 and exhibit a similar spatial perception difference as Groups 2 and 3. Group 6 is at M-space level 4. These six groups will be used for later analysis.

As a result of this study, we recommend to other researchers that if they are interested in identifying the working memory capacity (M-space level) of young children they should give a battery of at least three M-space tests

(such as CS, BDS and MC). The DPT needs further work to overcome the technical problem associated with "understanding instructions" and in the meantime is clearly not suitable for use with the younger age group. Researchers should then use the pattern of responses on the set of tests to cluster students into groups. We believe this procedure is superior to using a single test to define the memory capacity for any group of students.

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APPENDIX A

Counting Span Test

— Protocol

— Response Sheet

— Sample Items

— Item Sets

COUNTING SPAN TEST

LET'S PLAY A GAME. I WANT YOU TO COUNT AND REMEMBER THINGS.

E lays out the first practice card in front of S.

SEE THIS CARD. I'M GOING TO SHOW YOU LOTS OF CARDS LIKE THIS. I WANT YOU TO TAKE YOUR FINGER AND COUNT EACH OF THE COLOURED SHAPES LIKE THIS.

E slowley counts the (coloured) shapes.

JUST COUNT THE (COLOURED) SHAPES, NOT THE GREY SHAPES. IGNORE THEM EVERY TIME YOU SEE THEM.

NOW I AM GOING TO COVER UP THIS CARD.

E places a blank card directly over the card just counted.

NOW ALL YOU HAVE TO DO IS TELL ME HOW MANY (BLUE) SHAPES WERE ON THE CARD. HOW MANY WERE ON IT.

If S responds incorrectly, have him count the card, cover it and ask the question again.

RIGHT! NOW I AM GOING TO MAKE IT A BIT HARDER. YOU COUNT THIS CARD.

E presents the first card of the second practice set.

REMEMBER HOW MANY WERE ON THE CARD AND COUNT THIS ONE.

E places the second card over the first. S counts it.

NOW I WILL COVER THEM BOTH UP.

E places a blank card over the second card.

YOU TELL ME HOW MANY WERE ON THE FIRST CARD AND THEN HOW MANY WERE ON THE SECOND CARD.

If S responds incorrectly, show him the cards again, then cover them and leave him to recall them.

NOW YOU SEE HOW THE GAME WORKS I AM GING TO SHOW YOU FROM 1 to 4 CARDS. YOU HAVE TO COUNT THEM, THEN TELL THEM BACK TO ME IN ORDER.

HERE LET'S TRY ANOTHER ONE.

E presents the next practice set. Again if S responds incorrectly show him the cards again, cover them and have him recall them.

THAT IS GOOD.

NOW LET US TO SEVERAL SETS. DON'T WORRY IF SOME ARE LONG AND HARD.

E proceeds in order outlined on the response sheet. E should say nothing, present next cards the moment the child has finished counting, S should count with their fingers and out loud. The blank card should be a signal to respond.

If S fails to respond quickly say.

HOW MANY WERE ON THE CARDS.

Use the Response Sheet to record responses.

.66

RESPONSE SHEET

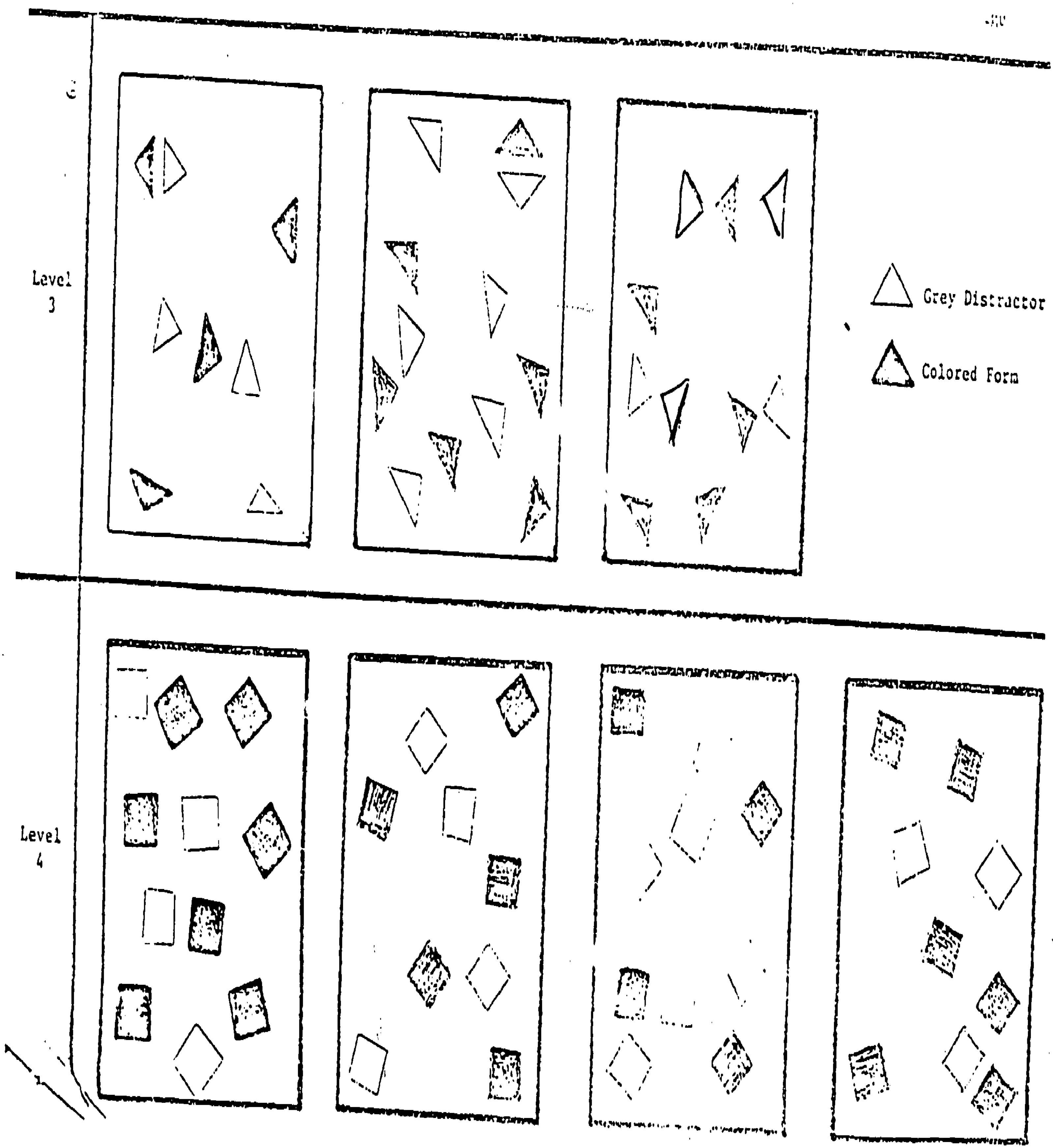
COUNTING SPAN TEST

Mark + for correct, 0 for incorrect

LEVEL	1	2	3	4	5
Set 1		___			
2				___	
3	___				
4					___
5		___			
6			___		
7					___
8	___				
9			___		
10				___	
11		___			
12				___	
13	___				
14					___
15		___			
16	___				
17					___
18			___		
19		___			
20			___		
21				___	
22	___				
23			___		
24					___
25				___	

After Set 10 following the above sequence only the next sets at an appropriate level are to be given. Also, after two 0's have been scored at a level only sets at the next lower level should be administered.

Sample Sets



Sets Employed in the Counting Span Test

Level	Card 1 N*	Card 1 D**	Card 2 N	Card 2 D	Card 3 N	Card 3 D	Card 4 N	Card 4 D	Card 5 N	Card 5 D
1	5	4								
	4	5								
	7	3								
	5	3								
	6	4								
2 ***	4	5	7	3						
	5	4	7	3						
	4	3	3	5						
	6	5	4	3						
	7	4	6	5						
	7	4	4	9						
	9	4	2	6						
3 ***	6	5	4	4	5	3				
	7	6	5	4	4	8				
	2	3	5	4	3	4				
	9	3	1	5	8	4				
	6	3	5	4	7	5				
	4	5	7	3	6	4				
	4	6	6	4	5	4				
4 ***	8	4	4	5	6	3	5	6		
	1	6	9	3	8	4	2	6		
	4	5	7	3	5	4	6	3		
	6	4	4	6	7	4	5	6		
	6	5	5	4	7	3	4	5		
	4	5	7	4	5	4	6	4		
	8	5	2	7	5	6	3	6		
5 ***	6	4	8	4	7	4	5	6	4	5
	8	3	7	5	5	4	6	3	4	3
	2	6	5	4	3	4	1	4	4	5
	4	4	3	6	5	4	7	4	6	5
	5	4	6	3	4	6	3	7	7	3
	7	4	5	5	6	4	4	5	8	4
	9	4	2	6	8	4	[illegible]	4	5	5

* Number of shapes to be counted
** Number of distractor shapes
*** No more than 5 items were given to any one child.

APPENDIX B

Mr. Cucui

— Protocol

— Response Sheet

— Sample Item

— Item Set

CUCUI

LET'S PLAY A GAME. THIS IS MR. CUCUI.

E places practice card 1 before S.

HE IS A VERY TRICKY FELLOW. HE IS GOING TO TRY TO TRICK YOU. BY CHANGING DIFFERENT PARTS OF HIS BODY DIFFERENT COLOURS. LOOK HERE.

E points to the right hand that is coloured red.

NOW HE IS GOING TO HIDE

E covers practice card with a blank outline.

CAN YOU POINT TO THE PART MR. CUCUI CHANGED?

If S answers incorrectly show him the practice card again, cover it and ask him again to point to the part.

NOW LOOK AGAIN

E presents the second practice card.

ONCE HE HIDES, YOU POINT TO THE PARTS OF HIS BODY THAT HE CHANGED DIFFERENT COLOURS.

E waits 5 seconds, covers the card with an outline.

POINT TO THE PARTS MR. CUCUI CHANGED.

If S answers incorrectly show him the practice card again, cover it and ask him again to point to the parts.

NOW LOOK AGAIN

E starts with card sequence indicated on the scoring sheet. For each card give S 5 seconds before covering it.

Record scores on the scoring sheet.

RESPONSE SHEET

CUCUI TEST

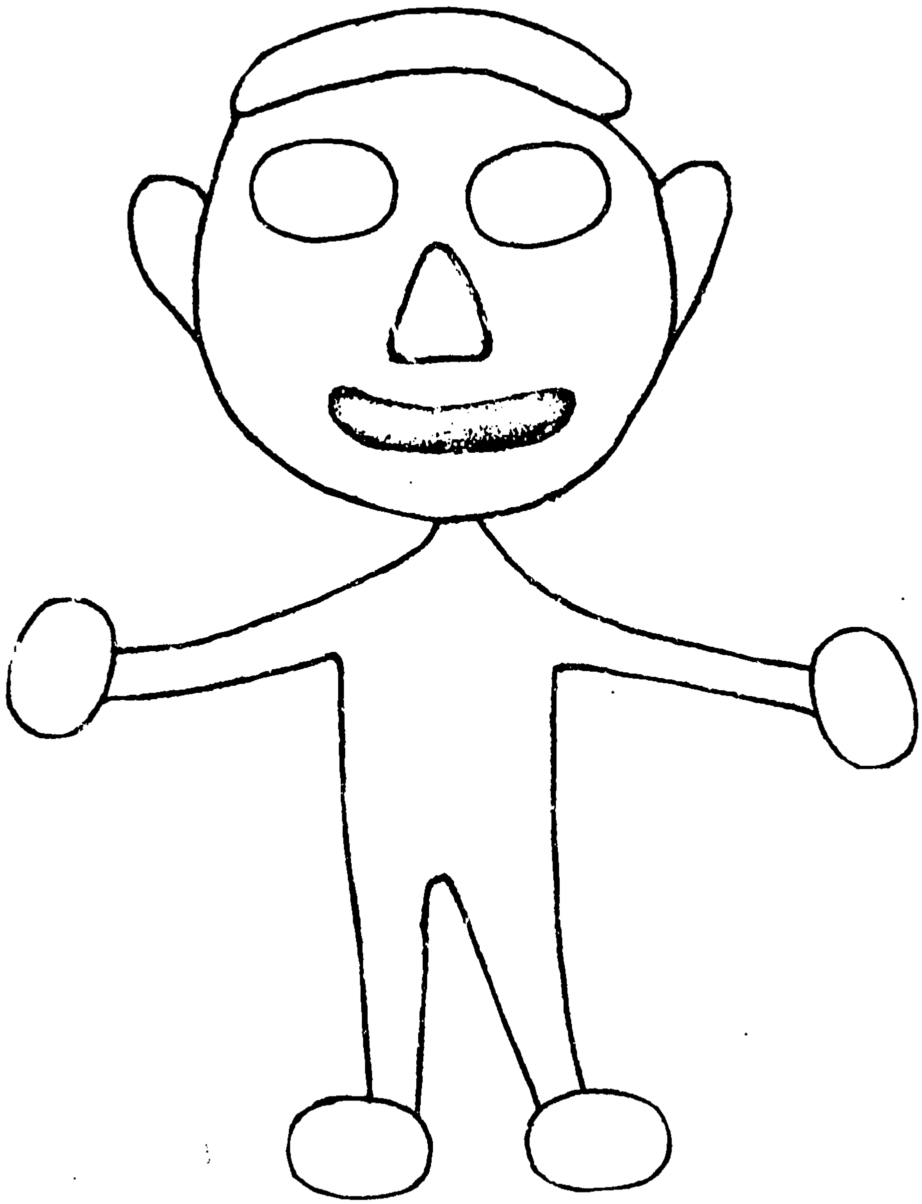
Score + for correct, 0 for incorrect

Start with Level 2, Item 1

Item	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
1	________	________	________	________
2	________	________	________	________
3	________	________	________	________
4	________	________	________	________
5	________	________	________	________

If S gets item correct, go up a level. If S gets item incorrect go down a level.

Once 2 0's have been scored at a level only items at lower levels should be administered.



Composition and Ordering of Items on the Cucui Test

Item No.	No. of Colored Body Parts	Location and Color of Colored Body Parts
1	2	left ear - blue: right foot - red
2	4	left ear - yellow: hair - green: right hand - orange left foot - blue
3	1	right eye - pink
4	3	left eye - red: right ear - green: left foot - brown
5	1	mouth - yellow
6	4	left ear - blue: right eye - green: nose - light blue right foot - yellow
7	2	hair - yellow: left hand - blue
8	3	left ear - yellow: left foot - brown: right hand - blue
9	1	nose - orange
10	3	left hand - pink: right eye - blue: mouth - purple
11	4	left year - pink: right eye - orange: right hand - yellow: left foot - blue
12	2	left eye - orange: right hand - blue
13	3	left ear - purple: nose - pink: left foot - orange
14	1	hair - green
15	4	left hand - brown: right hand - purple: right ear - blue: right foot - pink
16	2	right eye - yellow: mouth - blue
17	3	hair - blue: left eye - yellow: right foot - green left hand - brown
18	1	left foot - blue
19	4	hair - orange: right ear - blue: right foot - red: lef hand - brown
20	2	left hand - orange: nose - green
21 (6)	5	hair - purpole: right eye - blue: nose - green: left ear - red: right foot - light blue
22 (9)	5	right eye - orange: mouth - blue: left foot - pink left hand - light blue: right hand - yellow
23 (12)	5	left eye - brown: nose - orange: mouth - blue: left hand - blue: left foot - red
24 (15)	5	mouth - blue: hair - yellow: left eye - purple: left ear - green: right foot - pink
25 (18)	5	right eye - yellow: mouth - blue: left hand - blue: right hand - orange: right foot - light blue

APPENDIX C

Digit Placement Test

— Protocol

— Response Sheet

— Item Set

PROTOCOL

DIGIT PLACEMENT TEST

I AM GOING TO SHOW YOU SOME NUMBERS.

E places practice card 1 in front of S.

THE FINAL NUMBER IN RED IS OUT OF ORDER I WANT YOU TO PLACE THE RED NUMBER WHERE IT BELONGS.

E should respond it goes "between".

When S responds using "between" - E places practice card 2 in front of S.

THE FINAL NUMBER IN RED IS OUT OF ORDER I WANT YOU TO DECIDE WHERE IT GOES AND REMEMBER IT.

E turns card down from S's view.

TELL ME WHERE THE FINAL NUMBER SHOULD BE PLACED.

If S answers incorrectly, show him the card again, repeat that the final number is out of order, remove and ask again where it goes.

LET'S PRACTICE A FEW

E presents next 2 cards, waits 5 seconds, removes each card and provides correct responses for those which S answers incorrectly.

NOW LET'S TRY SOME MORE.

Use response sheet to record answers.

RESPONSE SHEET

DIGIT PLACEMENT TEST

Mark + for correct, 0 for incorrect

1 ____________

2 ____________

3 ____________

4 ____________

5 ____________

6 ____________

7 ____________

8 ____________

9 ____________

10 ____________

11 ____________

12 ____________

13 ____________

14 ____________

15 ____________

16 ____________

17 ____________

18 ____________

19 ____________

20 ____________

Stop after subject has 3 incorrect responses in a row.

Practice

1, 4 2
2, 5, 7 3
0, 3, 5 4
1, 4, 6 2

Level 2

2, 4, 7 6
0, 3, 8 7
1, 4, 9 2
3, 5, 8 4
4, 7, 9 8

Level 3

2, 4, 7, 9 3
0, 3, 5, 7 4
1, 4, 6, 9 7
1, 5, 7, 8 3
2, 3, 5, 9 6

Level 4

1, 4, 5, 7, 9 2
0, 3, 6, 8, 9 5
2, 3, 5, 7, 9 6
1, 3, 4, 7, 9 8
2, 5, 6, 8, 9 3

APPENDIX D

Backward Digit Span

— Protocol

— Response Sheet

PROTOCOL

BACKWARD DIGIT SPAN

I WILL SAY SOME NUMBERS AND I WOULD LIKE YOU TO REPEAT THE SAME NUMBERS, ONLY YOU ARE TO SAY THEM BACKWARDS.

LISTEN CAREFULLY TO THE NUMBERS I SAY. THEN SAY THE SAME NUMBERS ONLY REMEMBER TO SAY THEM BACKWARDS.

LET'S PRACTICE A FEW.

E presents the following series and provides correct response if S answers incorrectly.

4, 2

If S says 4, 2 repeat that you want them to respond backwards like 2, 4

then say:

8, 0

If S responds 8, 0 say BACKWARDS PLEASE (if necessary use other orders first-last name, shoes-socks ...)

When S is responding backwards give 2 more examples

2, 7

3, 9

THAT'S GOOD. NOW WE'll TRY SOME MORE. LISTEN CAREFULLY AND REPEAT THE NUMBERS YOU HEAR ONLY REMEMBER TO SAY THEM BACKWARDS.

Use the response sheet to read the digit series. For each series read one digit per second. Allow as much time as is needed between series.

Backward Digit Span

Mark + for correct, 0 for incorrect.

7, 8 ____	7, 1, 3 ____	3, 4, 6, 9 ____	5, 1, 3, 9, 2 ____
0, 7 ____	5, 8, 7 ____	1, 8, 4, 3 ____	7, 3, 5, 0, 8 ____
4, 3 ____	8, 6, 2 ____	9, 5, 3, 2 ____	2, 6, 4, 7, 8 ____
5, 1 ____	8, 1, 7 ____	9, 6, 7, 4 ____	5, 3, 6, 8, 2 ____
6, 9 ____	0, 5, 3 ____	7, 3, 0, 5 ____	1, 4, 5, 2, 0 ____
8, 2 ____	8, 4, 1 ____	3, 1, 2, 5 ____	3, 1, 8, 9, 5 ____
5, 0 ____	2, 4, 3 ____	2, 3, 8, 1 ____	6, 5, 7, 9, 2 ____
1, 4 ____	6, 2, 0 ____	6, 0, 2, 1 ____	6, 7, 1, 5, 0 ____
9, 8 ____	1, 7, 6 ____	6, 5, 7, 9 ____	3, 5, 0, 9, 6 ____
5, 6 ____	3, 8, 1 ____	8, 7, 4, 3 ____	1, 8, 3, 7, 4 ____

Terminate the task after three consecutive errors and record a '-' for that column.

Move to the next series after 6 consecutive correct responses and score a '+' for that column.

Otherwise complete all 10 in the column and record the number of correct responses. Move to the next column only if 6 or more responses were correct.

APPENDIX E

Scoring Rules for the Four Tests

Scoring Rules for the Counting Span Test

1) S-1 # correct

2) S-2 = $x_1 + x_2 + x_3 + x_4 + x_5$

where x_1 = score for items 1-5

x_2 = score for items 6-10

x_3 = score for items 11-15

x_4 = score for items 16-20

x_5 = score for items 21-25

score (x_i) = 1 if 4/5 or 5/5 are correct

(x_i) = 0 if o/5 are correct

(x_i) = .2 if 1/5 are correct

(x_i) = .4 if 2/5 are correct

(x_i) = .6 if 3/5 are correct

do not score x_{i+2} if $x_{i+1} < 1$.

3) S-3 = $z_1 + z_2 + z_3 + z_4 + z_5$

but z_i = 1 if 4/5 or 5/5 are correct

z_i = 0 otherwise

do not score z_{i+1} if $z_i \neq 1$

4) $L = \frac{n_1}{5} + \frac{n_2}{5} + \frac{n_3}{5} + \frac{n_4}{5} + \frac{n_5}{5}$

n_1 = number correct of items 1-5

n_2 = number correct of items 6-10

n_3 = number correct of items 11-15

n_4 = number correct of items 16-20

n_5 = number correct of items 21-25

S-4 = $[L]$

Scoring Rules for Digit Placement

1) S-1 = # correct

2) $S\text{-}2 = 1 + x_1 + x_2 + x_3$

x_1 = score for items 1-5

x_2 = score for items 6-10

x_3 = score for items 11-15

score x_i = 1 if 4/5 or 5/5 are correct

x_i = 0 if 0/5 are correct

x_i = .2 if 1/5 are correct

x_i = .4 if 2/5 are correct

x_i = .6 if 3/5 are correct

do not score x_{i+2} if $x_{i+1} < 1$.

3) $S\text{-}3 = 1 + z_1 + z_2 + z_3$

but score

z_i = 1 if 4/5 or 5/5 are correct

z_i = 0 otherwise

do not score z_{i+1} if $z_i \neq 1$.

4) $$L = 1 + \frac{n_1}{5} + \frac{n_2}{5} + \frac{n_3}{5}$$

n_1 = # correct of items 1-5

n_2 = # correct of items 6-10

n_3 = # correct of items 11-15

$$S\text{-}4 = \lfloor L \rfloor$$

Scoring Rules for Mr. Cucui Test

1) S-1 = # correct

2) $S\text{-}2 = 1 + x_1 + x_2 + x_3 + x_4$

where x_1 = score for items 1-5

x_2 = score for items 6-10

x_3 = score for items 11-15

x_4 = score for items 16-20

score x_i = 1 if 4/5 or 5/5 is correct

x_i = 0 if 0/5 is correct

x_i = .2 if 1/5 is correct

x_i = .4 if 2/5 is correct

x_i = .6 if 3/5 is correct

do not score x_{i+2} if $x_{i+1} < 1$.

3) $S\text{-}3 = 1 + z_1 + z_2 + z_3 + z_4$

but score z_i = 1 if 4/5 or 5/5 are correct

z_i = 0 otherwise

do not score z_{i+1} if $z_i \neq 1$.

4) $L = 1 + \frac{n_1}{5} + \frac{n_2}{5} + \frac{n_3}{5} + \frac{n_4}{5}$

n_1 = # correct of items 1-5

n_2 = # correct of items 6-10

n_3 = # correct of items 11-15

n_4 = # correct of items 16-20

$S\text{-}4 = [L]$

Scoring Rules for <u>Backward Digit Span</u>

1) S-1 = # items correct * (*however, if in a column 6 items in a row are correct remaining items in column of 10 are to be considered correct)

2) $S\text{-}2 = 1 + x_1 + x_2 + x_3 + x_4$

where x_1 = score for items 1-10

x_2 = score for items 11-20

x_3 = score for items 21-30

x_4 = score for items 31-40

score x_i = 1 if 8/10, 9/10 or 10/10 are correct

x_i = 0 if 0/10 are correct

x_i = .1 if 1/10 are correct

x_i = .2 if 2/10 are correct

x_i = .3 if 3/10 are correct

x_i = .4 if 4/10 are correct

x_i = .5 if 5/10 are correct

x_i = .6 if 6/10 are correct

x_i = .7 if 7/10 are correct

do not score x_{i+2} if $x_{i+1} < 1$.

3) $S\text{-}3 = 1 + z_1 + z_2 + z_3 + z_4$

where z_i = 1 if 8/10, 9/10 or 10/10 are correct

z_i = 0 otherwise

do not score z_{i+1} if $z_i \neq 1$.

4) $L = 1 + \frac{n_1}{5} + \frac{n_2}{5} + \frac{n_3}{5} + \frac{n_4}{5}$

n_1 = number correct* of items 1-10

n_2 = number correct* of items 11-20

n_3 = number correct* of items 21-30

n_4 = number correct* of items 31-40

*see S-1 above for what is considered correct

$S\text{-}4 = \left[L \right]$